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ROYAL AIRCRAFT ESTABLISHMENT

FARNBOROUGH, HANTS

TECHNICAL NOTE No: G.W.94

CONTROLLED FRAGMENTATION OF HIGH CAPACITY CYLINDRICAL CASED CHARGE

(O.B.PROC. Q.6451)

by

R.G.KEATS, B.Sc.

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Technical Note No. G.W.94

December, 1950.

ROYAL AIRCRAFT ESTABLISHMENT, FARNBOROUGH

Controlled Fragmentation of High Capacity Cylindrical Cased Charge (O.B.Proc. Q.6451)

by

R.G.Keats, B.Sc.

R.A.E. Ref: GW/S.100/10/140

SUMMARY

A high capacity cased charge was detonated at Shoeburyness Proof and Experimental Establishment on 4th April 1950. The object of this trial was to determine the efficiency of control to approximately 1/32 oz fragments and to measure the velocity, angular distribution and penetration of such fragments. This Note describes the results obtained.

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1 Introduction

Theoretical investigations of the performance of fragmenting Guided Weapon Warheads[2] made early in 1949 suggested that a high capacity warhead controlled to give fast fragments weighing approximately 1/32 oz would be efficient against high altitude bombers. Many of the theoretical assumptions underlying this suggestion were extrapolations of existing data from trials carried out at much lower capacities and fragment velocities. In order to confirm these assumptions R.A.E. requested the Ordnance Board to arrange for the static detonation of a high capacity cylindrical cased charge controlled to give small high velocity fragments. The charge was prepared at S.M.R.T.B., Buxton, who have carried out previous trials[1,3] to determine means of controlling the fragmentation of cased charges, and the trial took place at Shoeburyness on April 4th, 1950, in a layout of strawboard and 3/16" mild steel targets. The fragment velocities were measured by means of the high speed camera technique in use for shell velocity measurements[1] and it was expected that the efficiency of control would be determined by an examination of the fragments collected in the strawboard.

Since the initiation of this trial further experimental tests of the damaging power of small fast fragments have modified the conclusions of the theoretical study. It is however thought worth recording in some detail the method and results of the trial as a guide to future work.

2 Summary of the Method

2.1 The Charge

A sketch of the cased charge used in this trial is reproduced as Fig.1. The R.D.X./T.N.T. 55/45 filling consisted of thin grooved cheeses of 10.45" diameter and was contained in a cylindrical mild steel case 11.4" long and $\frac{1}{8}$" thick. The ratio $\dfrac{\text{weight of charge}}{\text{weight of case}}$ was therefore approximately 4. Metal plates approximately $\frac{1}{2}$" thick were placed at each end of the cylinder and the detonator at the top was surrounded by a C.E. booster charge.

2.2 The Layout

The layout consisted of 9 strawboard packs and 7 mild steel plates of 3/16" thickness as shown in Fig.2. The four high speed cameras were used to determine the time between detonation and the impact of fragments on the mild steel plates X, Y, Z and K. The charge was supported with the weld pointing towards the mild steel target M and ricochet traps 3 feet high were placed 9 feet in front of the targets at 30 feet range.

2.3 The Procedure after Detonation

After detonation the strawboard targets were examined and the following data recorded.

2.31 The co-ordinates of each hole in the pack measured to nearest $\frac{1}{2}$ inch.

2.32 The weight of metal recovered from each hole to nearest 0.01 oz.

2.33 The number of sheets of strawboard penetrated by individual fragments.

3 Analysis of Results

3.1 Angular Fragment Distribution

Table I is a record of the angular distribution of the fragments collected from the strawboard packs, showing the mass collected between 2° intervals in the angle of depression from the centre of the charge.

The heights at which the strawboard packs were placed had been calculated on the assumption that the fragments would travel at a mean angle of depression equal to

$$\sin^{-1} \frac{V_F}{2\ V_D} \quad [4] .$$

where V_F = estimated initial velocity of the fragments.

V_D = velocity of the detonation wave in the explosive charge.

This angle is approximately 13° and the height of the layout should have been adequate to cover a dispersion of more than 4° about this angle. However, it was obvious immediately after detonation that the angle of 13° was an over estimate and that some considerable proportion of the fragments had cleared the top of the layout. This was subsequently confirmed by three observations.

(a) The path of the luminous fragments can be seen on the photographic records, Figs.3 to 7, and these paths indicate that the fragments at the top of the beam are travelling upwards.

(b) A comparison of the mass collected with the mass expected to be collected from any pack shows a discrepancy of approximately 40%.

(c) Several fragments were found in an adjacent layout 120 feet from the charge. The height of these fragments indicated that they had travelled almost horizontally.

Since the determination of V_F by the high speed cameras does not indicate any significant error in the original estimate of fragment velocity it appears certain that the formula $\sin^{-1} \frac{V_F}{2\ V_D}$ is in error. Further, since an examination of the photographs Figs.3 to 7 indicate that some considerable proportion of the fragments were travelling upwards, the modification $0.58 \sin^{-1} \frac{V_F}{2\ V_D}$ [5] seems little better. However, a formula suggested by Shapiro[6]; viz. $\tan \phi = \frac{V_F}{2\ V_D} \frac{a - c}{b}$ (Fig.9), which reduces in the case of a cylinder to

$$\tan \phi = \frac{V_F}{2\ V_D} \cos \alpha \quad . \qquad (1)$$

where ϕ = the angle which the path of the fragment makes with the horizontal .

α = the angle which the line joining the point of detonation to fragment of case makes with the axis of the cylinder

appears to be consistent with the data from this trial when the point of detonation is taken to be at the base of the C.E. pellet. A graph of angle of depression against the total mass of fragments which would be collected above that angle for this formula, is shown in Fig.8 together with the experimental points obtained in the trial. The difference between mass collected and that originally expected to be collected was used as an estimate of the mass clearing the layout in plotting the trial points on this figure. Of the upper half of the beam little can be said except that the photographic records are not at variance with (1). The packs ABC at 10 feet were blown down by the blast, and fragment collection from these packs is probably incomplete - they have therefore been omitted from this analysis.

An analysis of the total mass collected by each pack does not reveal any significant difference in the azimuth distribution of fragments and this is confirmed by Table II which shows the distribution of strikes and throughs on the mild steel plates.

3.2 Fragment Mass Distribution

3.21 Two histograms of fragment mass distribution have been compiled. Fig.10 shows the division of fragments actually collected into different mass categories while in Fig.11 an attempt has been made to allow for secondary break-up in the strawboard by combining as one fragment the total mass found in each hole. The correct distribution probably lies between these two extremes and the analysis of Appendix I indicates that while in Fig.10 the effect of secondary break-up is over estimated the results of the trial are incompatible with the hypothesis of a random space distribution of the fragments as collected.

3.22 The following factors were among those which prevented the achievement of good control.

3.221 The internal surface of the case was rough and slightly oval whereas the charge was perfectly circular and there were therefore comparatively large gaps between the charge and the casing.

3.222 The necessity to use precast cheeses introduced considerable difficulties in the manufacture and correct fitting of the cheeses.

3.223 The limitations of the grooved design were not fully appreciated at the time of the trial and it is now known that the grooves were too deep causing over control and dust.

Both the histograms and the information in Table II indicate that an unduly large proportion of the case was converted to very small fragments.

Although the present results may not appear very encouraging, it is confidently expected that if the factors mentioned above are eliminated from future trials there will be a considerable improvement in the control of fragment mass.

3.3 Fragment penetration into strawboard

In the case of fragments which were found singly in the strawboard packs it has been possible to complete Table III, which shows the mass of fragments, the range from charge to strawboard pack and the number of sheets of strawboard 1/6" thick penetrated by the fragments.

Several fragments were found to have penetrated the strawboard packs of a neighbouring layout 120 feet distant from the charge and in three instances these were recovered and included in Table III. The penetration of packs at 30 feet appears to be independent of fragment mass but no significance can be attached to a result based on so few observations[9].

The details of throughs and strikes on the mild steel plates are given in Table II. It would be expected that most of the fragments weighing over 0.01 oz would perforate these plates and it is therefore likely that the strikes were caused by very small particles.

3.4 Fragment Velocities

Figs.3-7 show the progress of the fragments as recorded by the camera photographing plate X and the paths of individual fragments may be distinguished on these records.

3.41 Three different methods were used to estimate fragment velocities from the photographic records and the results of each are given in Table IV.

3.411 The number of frames exposed from the time of detonation until a fragment hit the mild steel plates.

Unfortunately this method could only be used with a small proportion of the fragments because the luminous trails left by the fragments as they moved through the air obscured the flash as they hit the plates. There is an uncertainty of one frame in the time of detonation and the time of strike, which causes an error in the results obtained by this method.

3.412 The distance travelled by a fragment during the exposure time of a single frame.

In some instances this distance can be estimated from the length of the luminous track due to the movement of the fragment during the exposure time of a frame. This method could only be used in the case of the fastest fragments travelling normally across the field of view of the camera.

3.413 The distance travelled by individual fragments during the time interval between frames.

This method which can only be used with the fastest fragments is very useful for computing average velocities between 15 feet and 30 feet from the charge.

3.42 None of these methods was considered sufficiently accurate to compute a drag coefficient and it was therefore decided to use the formula $V = V_F \exp. (- 0.0056 \frac{\bar{a}}{m} r)$ [8] to compute initial velocities V_F. The value of $\frac{\bar{a}}{m}$ is 2 for the controlled fragments and this value has been used in computing V_F.

4 Conclusions

4.1 The initial fragment velocity does not differ appreciably from that predicted by Gurney, viz. 10,000 ft/sec.

4.2 The angular fragment distribution differs considerably from that predicted by the previously widely accepted formulae, and some formula which takes into account the point of detonation and the spherical nature of the detonation wave is required. The tentative formula of Shapiro[6] fits the available data reasonably well.

4.3 The control of fragmentation was less successful than had been hoped and an unduly large proportion of the case was converted to fine particles.

4.4 Penetration into strawboard where it could be successfully measured justifies the extrapolation of existing formulae[9]. For the controlled fragments

$$p \approx \frac{1}{900} \frac{mV}{\bar{a}}$$

where p = penetration in inches.

$\bar{a}$ = average presented area of fragment in square inches.

m = mass of fragment in ozs.

5 Acknowledgement

It is desired to acknowledge the help given by S.M.R.T.B. Buxton; Ordnance Board; Proof and Experimental Station, Shoeburyness and Armament Department R.A.E. in the preparation and completion of this trial.

References

No.	Author	Title, etc.
1		O.B. Investigation No.3203. O.B. Proc. Q.6451 (Special). 31st March, 1950.
2	W.R.B.Hynd	Report of the R.A.E. Project Group on Medium Range Anti-Aircraft Guided Missiles, Part IV. Appendix VI. Warhead Design. December, 1949.
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4	G.I.Taylor	Analysis of the explosion of a long cylindrical bomb detonated at one end. R.C.193. March, 1941.
5	D.J.Bishop D.F.Mills A.V.Fiest	A Review of Existing Fragmentation and Penetration Laws. A.D.E. Tech. Note T2/L12/AVF.

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No.	Author	Title, etc.
6	H.N.Shapiro	A Report on Analysis of the distribution of perforating fragments for the 90 mm M.71 Fuzed T.74E6. Bursting Charge T.N.T. UNM/T-234.
7	B.L.Welch	The comparative performance against thin mild steel plate of irregular fragments and small regular projectiles. A.C. 8110. 53/F.P.348. April, 1945.
8	E.S.Pearson D.J.Bishop	The Derivation of a retardation Law for fragments. E.B.D. Report 25 (O.B. Proc. 18524). July, 1942.
9	B.L. Welch	The penetration of shell fragments into strawboard. O.B. Proc. No.22897. April, 1943.

Attached:

Appendix I
Tables I - IV incl.
Drgs. GW/P/2114 to 2119
Negs. 90691 - 90692

Advance Distribution:

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Appendix I

Allowance for Secondary Break-up in the Strawboard packs

Figs.9 and 10 are so very different that the question naturally arises whether there is a large probability of two independent fragments striking a pack in such a manner that they form only one hole. This question will now be investigated under the assumption that any fragment striking a pack of area A has a probability $\frac{Ai}{A}$ of doing so within an area Ai.

This assumption might be challenged for several reasons including the following.

(a) Each fragment has its own most probable impact point and deviations from this point will follow an elliptical gaussian law of undetermined variances.

(b) There is some evidence that there can be apparent focussing of fragments and that for aerodynamic reasons fragments will tend to form clusters when travelling at high velocity on adjacent paths.

However the theoretical superiority of warheads controlled to give small fragments arises mainly from the belief that the fragments may be assumed to be distributed statistically uniformly throughout the fragment zone, and if this assumption is untenable then a powerful argument in favour of small fragments is destroyed. Sets of n small fragments of mass m ozs all following the same path in space will probably be less effective than single independent fragments of mass nm ozs. It is therefore suggested that, if through clustering, failure of control or for some other reason the incidence of multiple strikes is much greater than that expected under the random hypothesis then the efficiency of a warhead similarly designed needs further investigation.

It follows from the above assumption that the probability of any two fragments being found within a circle of radius r is $\frac{4\pi r^2}{A}$ and since there are $\frac{n(n-1)}{2}$ possible pairs from n fragments then the average number of occasions on which any two fragments will occupy the same circle is $\frac{n(n-1)}{2} \cdot \frac{4\pi r^2}{A}$. Further the expected number of occasions on which k fragments will occupy such a circle is equal to or less than

$$\frac{n!}{(n-k)!\ k!}\left(\frac{4\pi r^2}{A}\right)^{k-1}$$

The packs at 20 feet only have been considered in the following tables but those at 30 feet would give similar results. The first table shows the number of occasions on which the stated number of fragments were found in the same hole - all fragments weighing less than 0.01 ozs being ignored.

	Number of fragments							
	1	2	3	4	5	6	7	8
Pack D	14	3	1	2	2			
Pack E	12	8	2	1	2	1	0	1
Pack F	14	3	5	2	1	1		

On the basis of these figures a further table has been compiled for comparison with the theoretical expected figures. A survey of the larger holes in the packs suggests that one inch is a reasonable value for the radius of the circle and it should be noted that, for example, a hole containing four fragments represents six occasions on which two fragments are found together.

Number of fragments within circle	Pack D		Pack E		Pack F	
	Observed number of occasions	Expected number of occasions	Observed number of occasions	Expected number of occasions	Observed number of occasions	Expected number of occasions
2	38	8.5	83	19	55	15
3	29	<1.1	102	<4	43	<2.5
4	12	<0.1	96	<0.6	22	<0.3
5	2	<0.01	64	<0.07	7	<0.03
6			29	<0.007	1	<0.0025

These figures indicate that, while several instances of two fragments occupying one hole might be expected, the number of occasions on which this occurred is much greater than would be expected on the random hypothesis. It is suggested that the reasons for this discrepancy must be found and their effects greatly reduced before the lethality of any similar warhead can be expected to approach its theoretical value[2].

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Table I

Angular Distribution of Fragments Recovered from Strawboard Packs

Packs at 20 feet

Angular Zone in Degrees	Weight in Ounces		
	Pack D	Pack E	Pack F
2°48' - 4°48'	0.279	0.528	0.501
4°48' - 6°48'	0.531	0.222	0.303
6°48' - 8°48'	0.368	0.796	0.669
8°48' - 10°48'	1.170	0.740	1.128
10°48' - 12°48'	0.172	0.325	0.498
12°48' - 14°48'	0	0.023	0.064
14°48' - 16°48'	0.011	0.011	0.016
Totals	2.531	2.645	3.179

Packs at 30 feet

Angular Zone in Degrees	Weight in Ounces		
	Pack G	Pack H	Pack I
6°18' - 8°18'	0.372	0.435	0.290
8°18' - 10°18'	0.292	0.280	0.474
10°18' - 12°18'	0.576	0.146	0.205
12°18' - 14°18'	0.006	0.010	0.019
14°18' - 16°18'	0.003	0.002	0.006
Totals	1.249	0.873	0.994

Table II

Distribution of "Strikes" and "Throughs" on the Mild Steel Plates

Plates at 20 ft

	Throughs									Strikes				
	Size of larger axis of hole (ins)									Size of larger axis of hole (ins)				
Plate	0.25	0.50	0.75	1.00	1.25	1.50	1.75	2.00	2.25	0.1	0.2	0.3	0.4	0.5
Y	6	15	4	2	5	3	2	-	1	308	43	14	-	-
Z	-	8	9	8	7	3	2	-	-	122	60	27	25	5

Plates at 30 ft

	Throughs												Strikes				
	Size of larger axis of hole (ins)												Size of larger axis of hole (ins)				
Plate	0.25	0.50	0.75	1.00	1.25	1.50	1.75	2.0	2.25	2.50	2.75	3.00	0.1	0.2	0.3	0.4	0.5
J	1	9	5	4	5	2	-	-	-	1	-	-	234	51	14	5	-
K	-	9	6	10	3	2	-	1	-	-	2	-	141	40	13	-	-
L	-	4	6	8	3	1	-	1	-	-	-	-	100	23	13	1	-
M	3	9	12	4	-	2	1	-	1	-	-	-	364	55	7	1	-
X	2	6	6	3	5	5	-	1	-	-	-	-	95	25	6	1	-

Table III

Observed Penetration of Fragments into Strawboard

Packs at 20 ft

	Weight Category (ozs)				
	0.01-0.02	0.02-0.03	0.03-0.04	0.04-0.05	0.05-0.06
No. of Sheets Penetrated	15	37	20	19	46
	29	24	18	25	
	22	24	32	26	
	30	23	27	19	
	21	16	17	34	
	31	24	37	23	
		23	20	19	
			22	27	
			23	20	
			29		
			25		
			26		
			20		
			28		
Average	25	24	25	24	46

Packs at 30 ft

	Weight Category (ozs)							
	0.02-0.03	0.03-0.04	0.04-0.05	0.06-0.07	0.07-0.08	0.10-0.11	0.14-0.15	0.22-0.23
No. of Sheets Pene-trated	22	22	18	25	26	31	23	21
	22							
	26							
Average	23	22	18	25	26	31	23	21

Packs at approx. 120 ft

	Weight Category (ozs)	
	0.03-0.04	0.04-0.05
No. of Sheets Penetrated	10	3
	11	
Average	10.5	3

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Table IV

Estimates of Fragment Velocity

METHOD I

Number of Fragments	Range to Target in Feet	Average velocity over stated range in feet per second	Expected R.M.S. error in estimating Aver. Vel. of one Fragment
2	30	9,700	565
15	30	8,500	433
9	30	7,600	342
1	30	10,600	716
2	30	9,000	526
23	30	7,900	403
2	20	11,500	1164
22	20	9,200	745
1	20	7,600	517

Estimated Average Initial Velocity = 10,000 feet per second

METHOD II

Range From Charge in Feet	Velocity of Fragment in feet per second	Estimated Initial Velocity in feet per second
14.8	8533	10,076
18.2	7187	8,816
18.4	8597	10,564
18.4	7247	8,908
21.4	8554	10,875
22.4	8854	11,377
22.4	7187	9,236
24.5	7571	9,959
24.7	7090	9,351
25.4	8078	10,732
25.6	8533	11,368
26.4	8316	11,182
28.2	7635	10,468
28.2	6737	9,242
28.4	6993	9,616

Estimated Average Initial Velocity = 10,120 feet per second.

METHOD III

Distances from Charge Between which Velocity was Measured in Feet	Average Velocity in Feet per second	Estimated Initial Velocity in Feet per second
15.5 - 26.7	8438	10,694
15.7 - 26.4	8438	10,190
15.2 - 28.7	7572	9,709
15.3 - 26.1	8137	10,235
15.3 - 26.1	8137	10,266
15.4 - 26.3	8212	10,379
19.2 - 26.8	7939	10,321
19.3 - 27.2	8316	10,786
19.0 - 26.9	8349	10,775
18.9 - 26.5	8000	10,313
18.8 - 26.6	8123	10,515
18.7 - 25.7	7356	9,444
18.5 - 25.8	7678	9,844
18.8 - 26.4	7969	10,288

Estimated Average Initial Velocity = 10,270 Feet per second.

SCALE: HALF SIZE

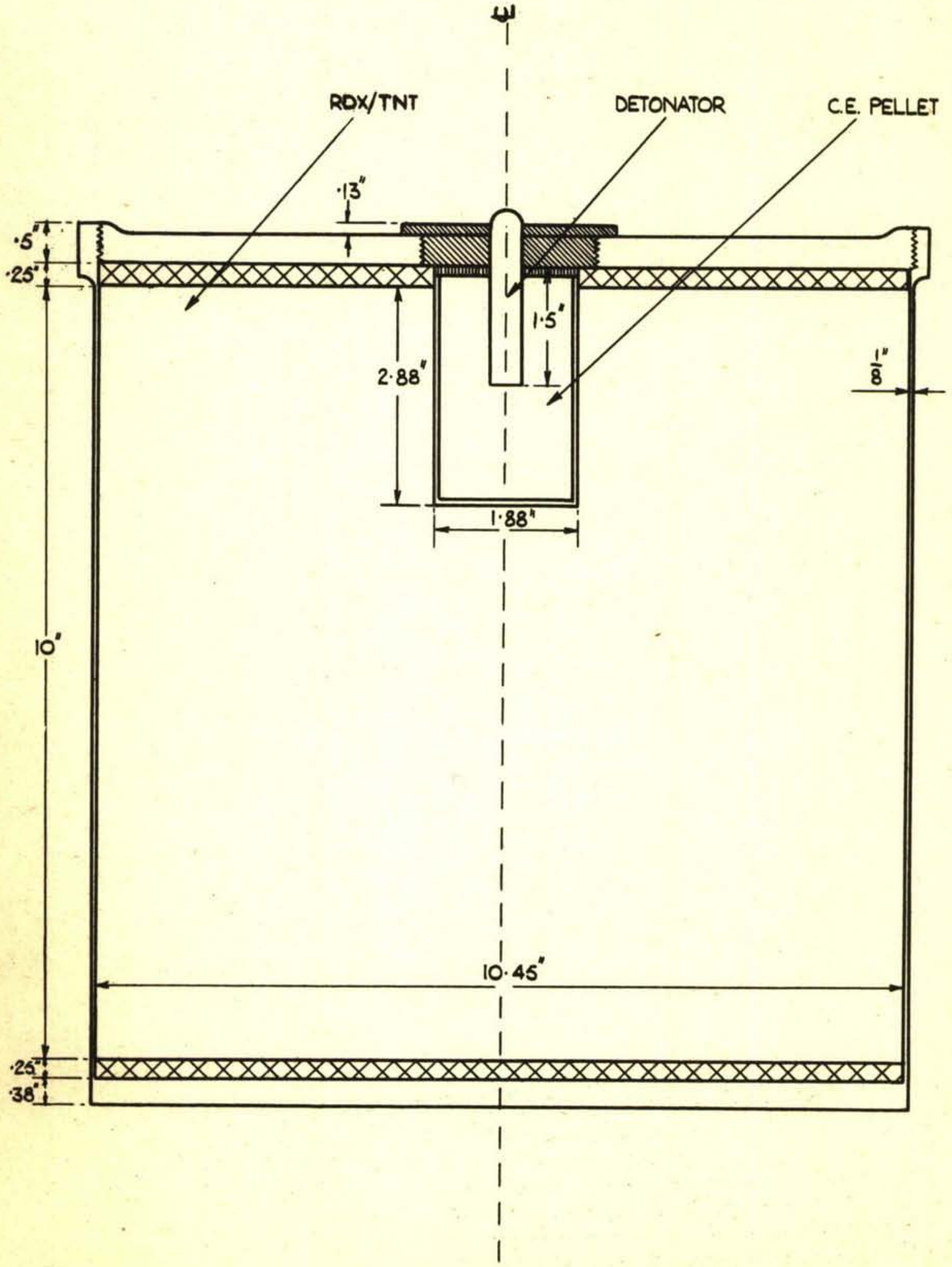
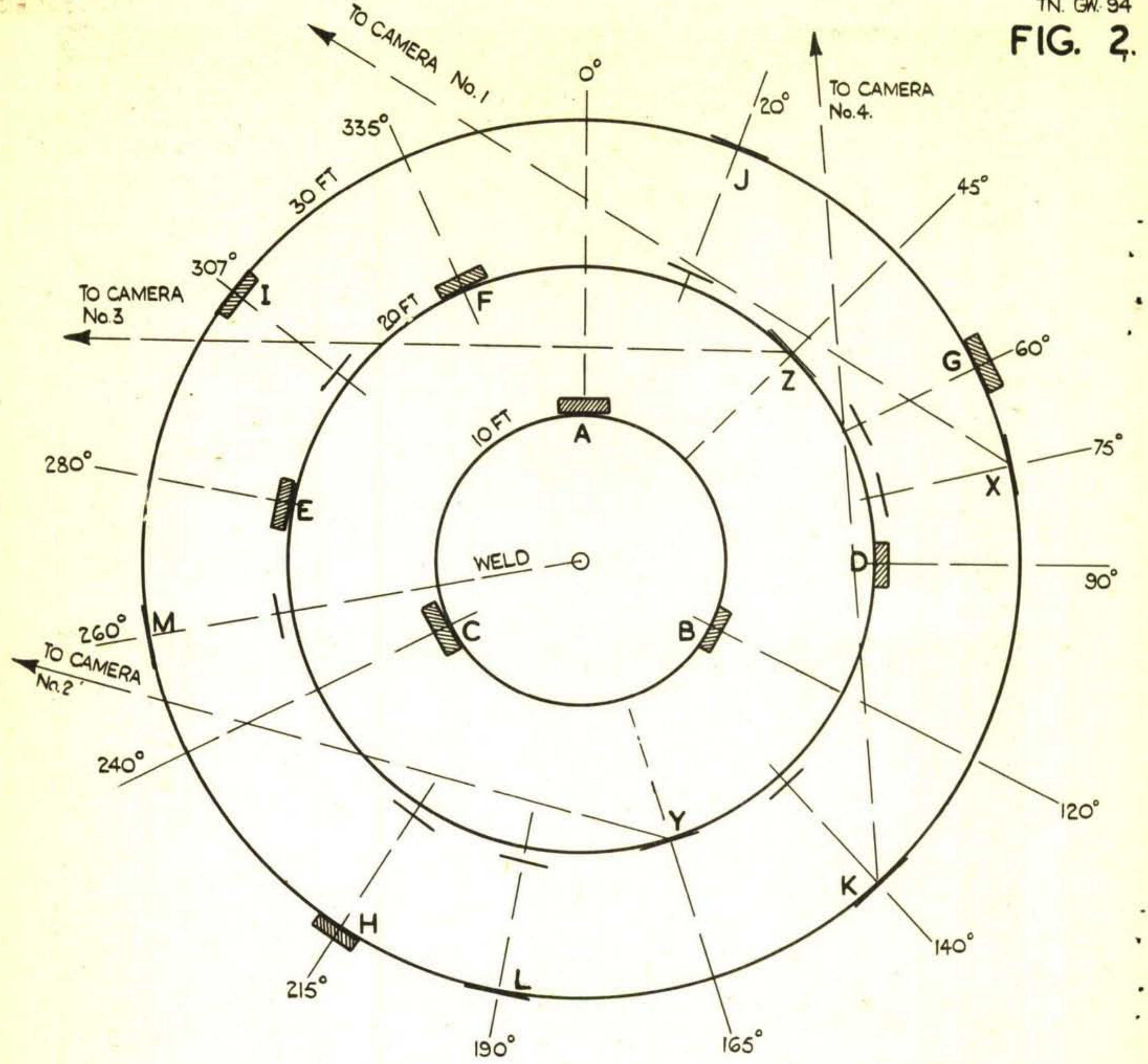
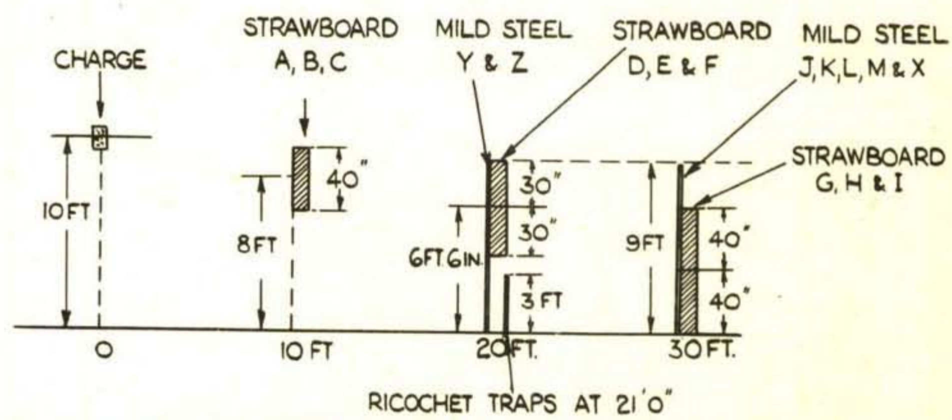


FIG. 1. HIGH CAPACITY CYLINDRICAL CASED CHARGE AS DETONATED.

FIG. 2.





	TARGET	HORIZ.	VERT.	THICKNESS	DISTANCE FROM CHARGE	HEIGHT OF CENTRE OF PACK ABOVE GROUND	No. OF PACKS
STRAWBOARD PACKS	A, B, C	30 INS	40 INS	12 INS	10 FT	8 FT	1
	D, E, F	40 INS	60 INS	12 INS	20 FT	6 FT 6 INS	2
	G, H, I	30 INS	80 INS	12 INS	30 FT	40 INS BASE RESTING ON GROUND	2
MILD STEEL PLATES	J, K, L, M, X	4 FT.	9 FT.	$\frac{3}{16}$ INS	30 FT	BASE RESTING ON GROUND	-
	Y & Z	4 FT.	9 FT.	$\frac{3}{16}$ INS	20 FT.	BASE RESTING ON GROUND	-

FIG. 2. LAYOUT FOR DETONATION OF CHARGE.

FIG.3. FRAME No.3

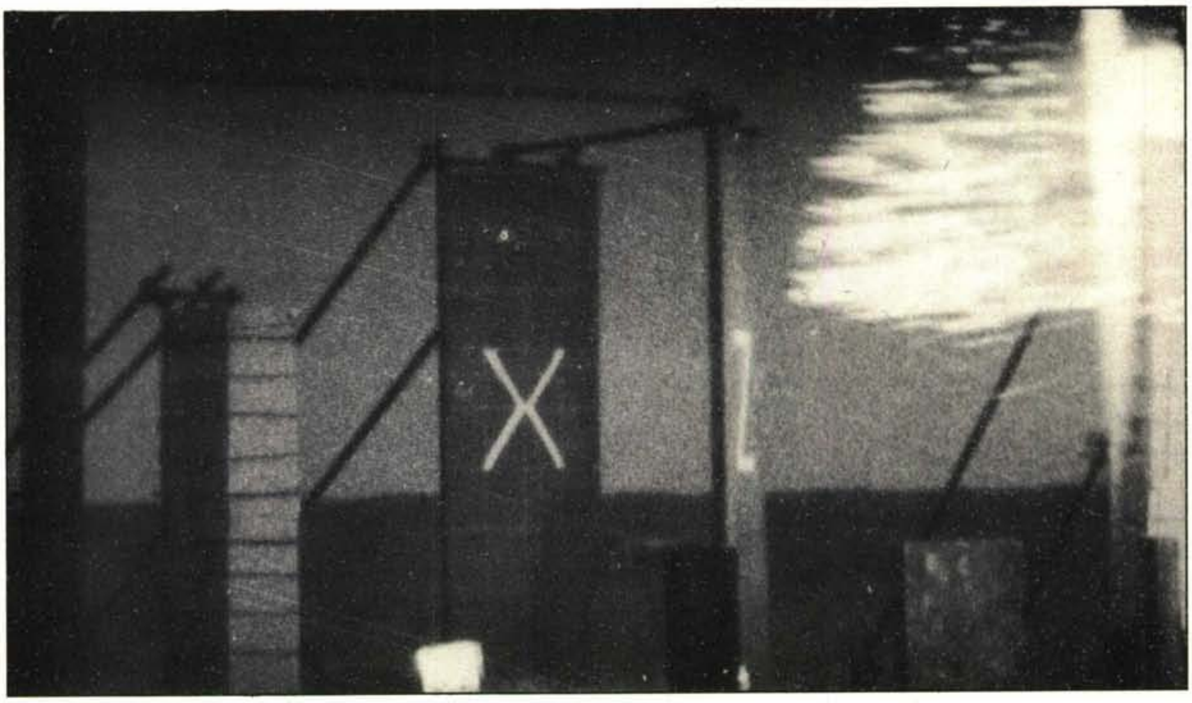


FIG.4. FRAME No.4

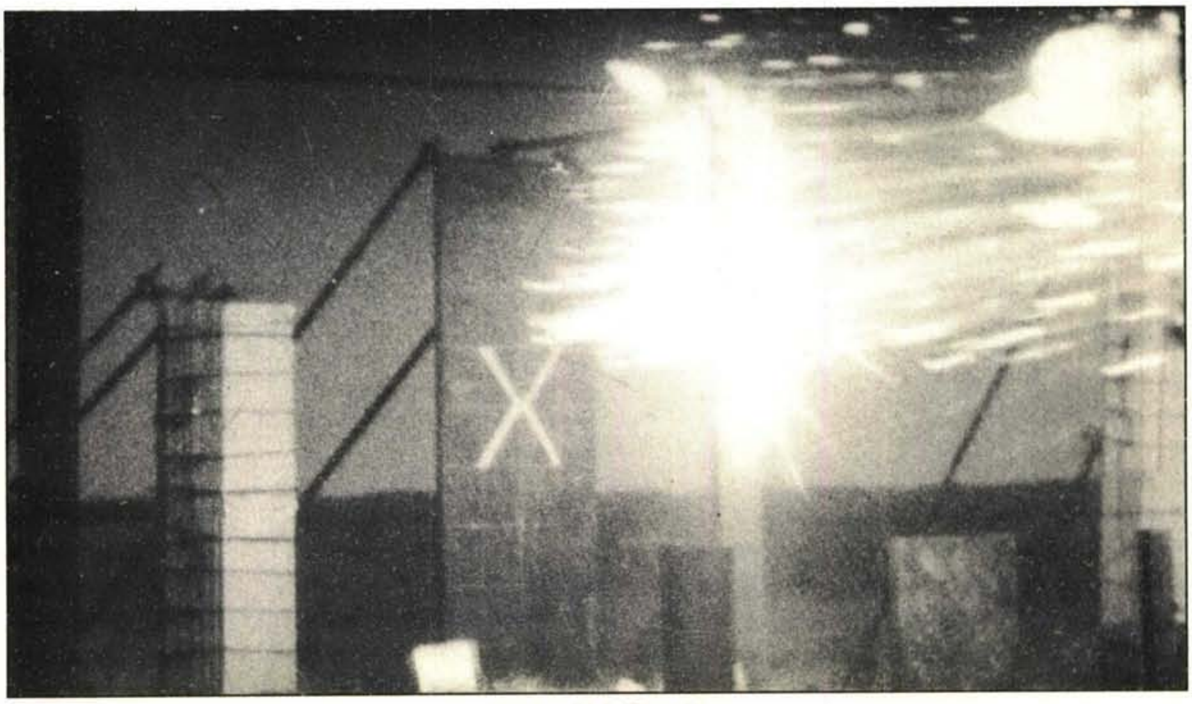


FIG.5. FRAME No.5

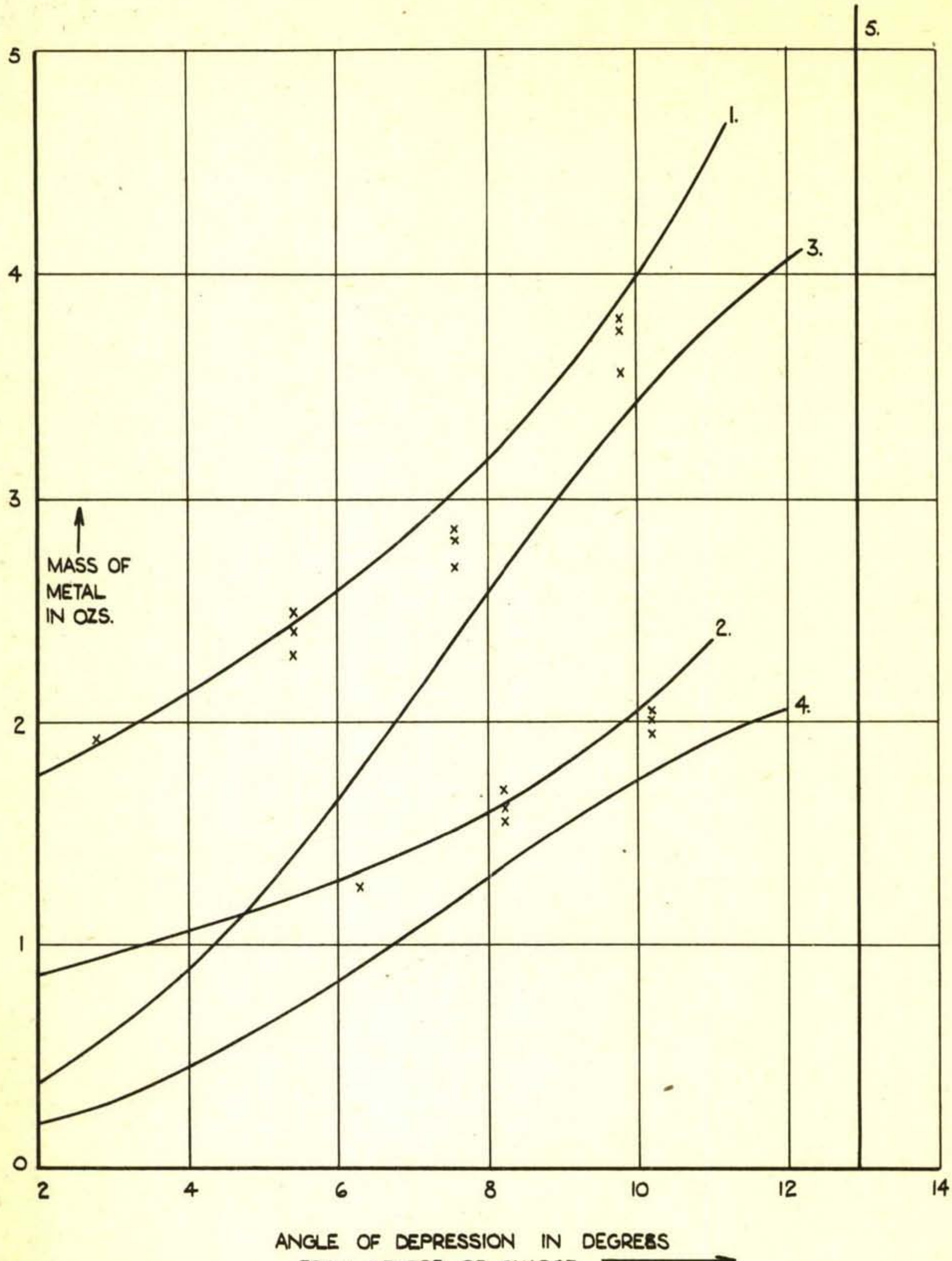
FIG.3, 4 & 5. PHOTOGRAPHS OF FRAGMENT BEAM

FIG.6. FRAME No.6

FIG.7. FRAME No.7

FIG.6 & 7. PHOTOGRAPHS OF FRAGMENT BEAM

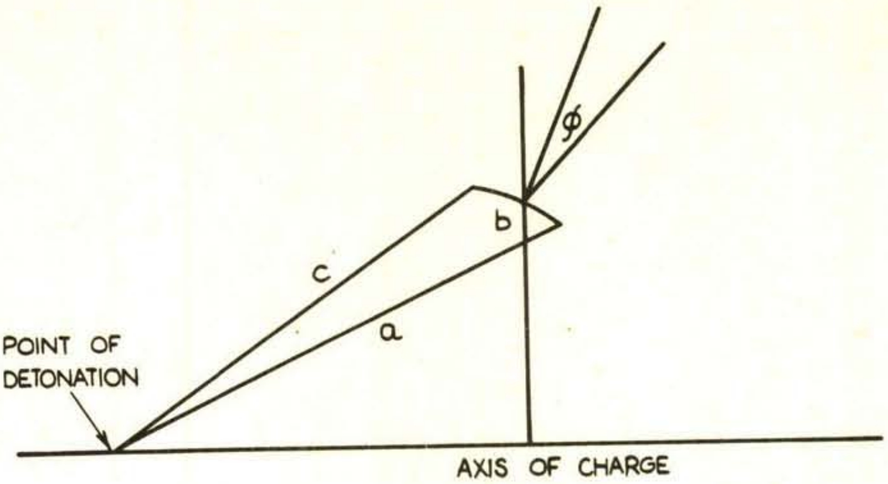
FIG. 8.



X TRIAL POINTS

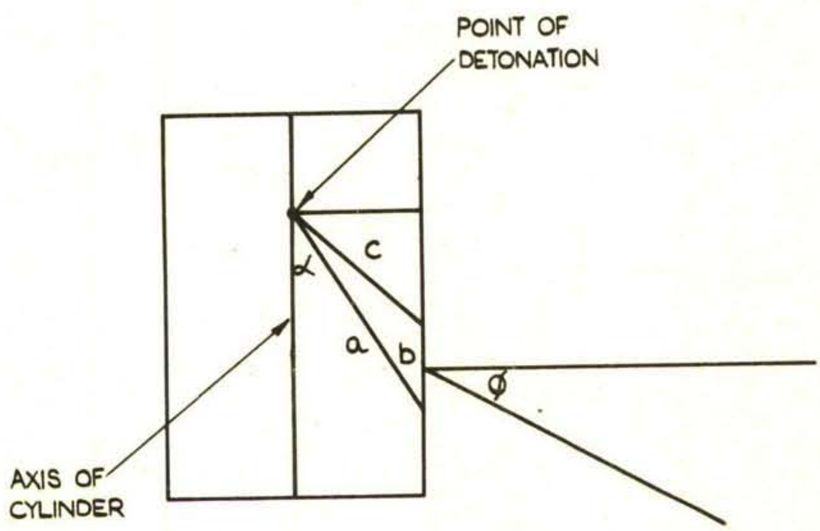
1. THEORETICAL CURVE FOR PACKS AT 20 FEET ACCORDING TO H.N. SHAPIRO
2. THEORETICAL CURVE FOR PACKS AT 30 FEET ACCORDING TO H.N. SHAPIRO.
3. THEORETICAL CURVE FOR PACKS AT 20 FEET BASED ON MEAN ANGLE OF THROW OF $0{\cdot}58 \sin^{-1}\frac{V_F}{2V_D}$ WITH STANDARD DEVIATION OF 4°
4. THEORETICAL CURVE FOR PACKS AT 30 FEET BASED ON MEAN ANGLE OF THROW OF $0{\cdot}58 \sin^{-1}\frac{V_F}{2V_D}$ WITH STANDARD DEVIATION OF 4°
5. $\sin^{-1}\frac{V_F}{2V_D}$

FIG. 8. VARIATION IN MASS OF METAL RECOVERED FROM PORTION OF STRAWBOARD PACKS ABOVE ANGLE OF DEPRESSION FROM CHARGE AS THAT ANGLE INCREASES.



$$\tan\phi = \frac{V_F}{2V_D} \quad \frac{a-c}{b}$$

(a).



$$\tan\phi = \frac{V_F}{2V_D} \quad \frac{a-c}{b}$$

$$= \frac{V_F}{2V_D} \cos\alpha$$

(b).

FIG. 9(a & b). FIGURE ILLUSTRATING FORMULA FOR ANGULAR DISTRIBUTION OF FRAGMENTS ACCORDING TO H.N. SHAPIRO.

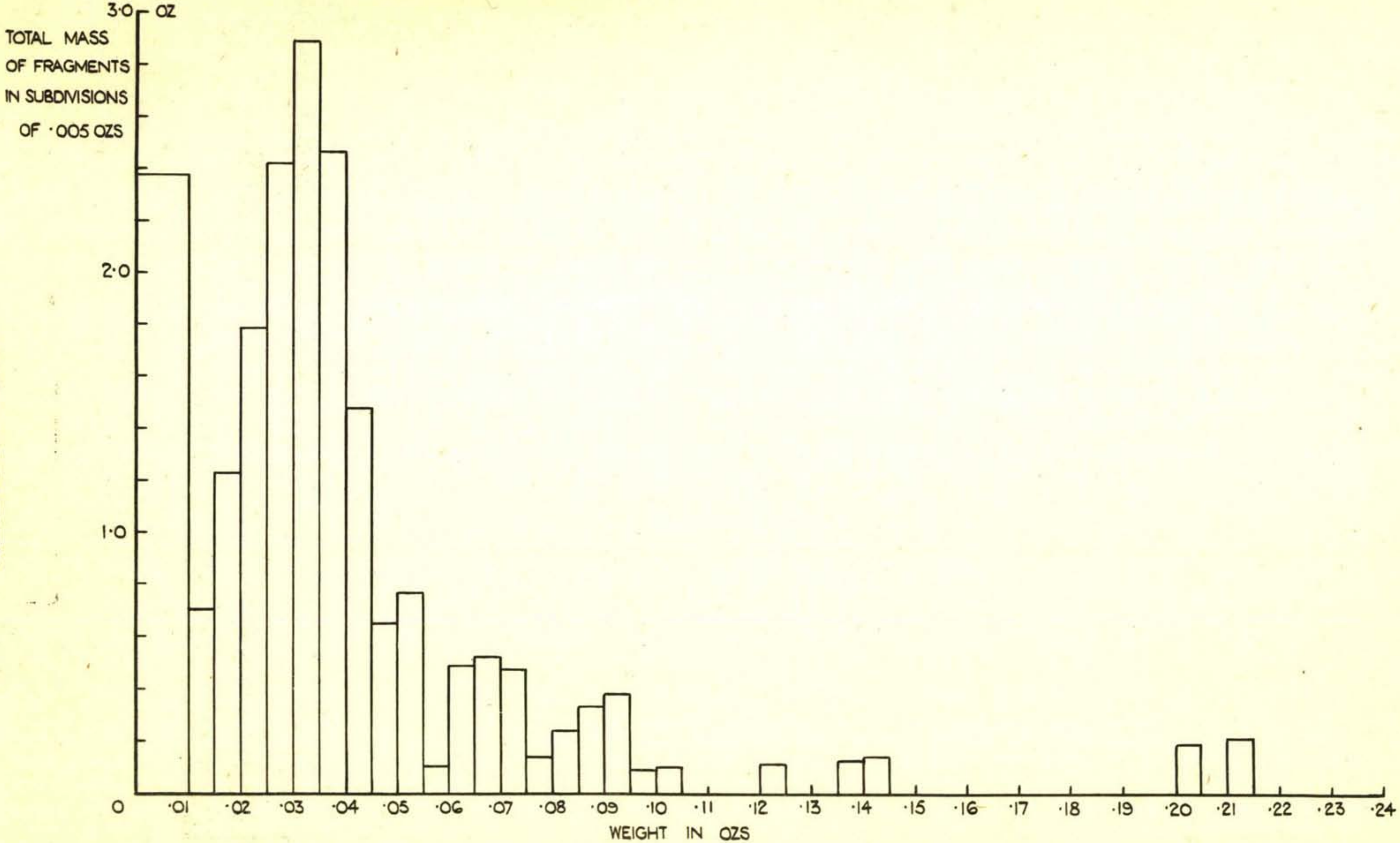


FIG.10. DIVISION OF MASS OF RECOVERED FRAGMENTS INTO MASS CATEGORIES

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FIG.11.

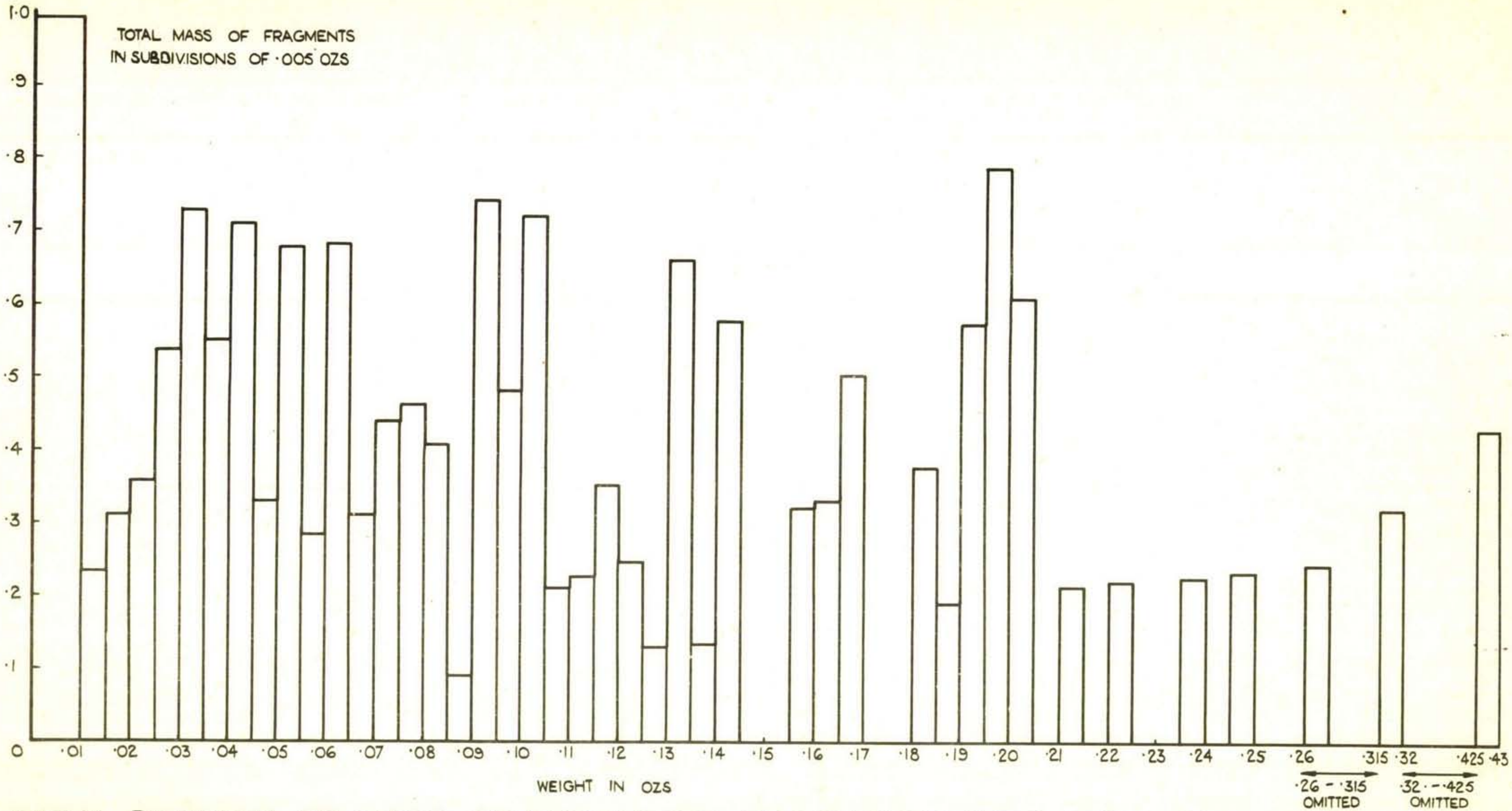

FIG.11. DIVISION OF MASS OF RECOVERED FRAGMENTS INTO MASS CATEGORIES, MAXIMUM CORRECTION BEING MADE FOR SECONDARY BREAK UP IN THE STRAWBOARD.

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